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The Risks of the Rose City: Assessing the Social Vulnerability of Communities to Multiple Environmental Hazards in the Portland Metropolitan Area

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by

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Abstract

In the past three decades, research in the geography of hazards and disasters has expanded beyond the response to hazard events and incorporated the concepts of preparedness, recovery, and mitigation. These issues require a complete understanding of the vulnerability of places to hazards, not only in regards to hazard characteristics but in regards to social and economic conditions as well. This paper offers a case study in hazard exposure and social vulnerability analysis which incorporates the methodology of two previous studies on the same topics. A geographic information system was used to determine vulnerable areas and populations exposed to five environmental hazards, assessed by five demographic indicators, within the Portland metropolitan area. The results portray broad spatial variations in exposure to different hazards, while they also suggest that several areas exhibit a combination of high levels of vulnerability and exposure to multiple hazards. Various factors in the interpretation of the results are discussed, including patterns of development, geographical units of analysis, differences in hazard probability and magnitude, and others. It is anticipated that the findings of this paper may be applicable to emergency planning and communication efforts within the region.

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Introduction

This study entails a descriptive analysis of several natural and technological hazards present within the Portland metropolitan area and the risks they pose to its residents. This was done by integrating natural hazards data, technological hazards data, and demographic data into a single geographic information system (GIS). It is expected that this study will enhance the understanding of the total vulnerability (or the vulnerability of place) of the metropolitan area, for the purpose of improving local emergency management planning and practices. The results produced from this research could also benefit vulnerable residents and communities by informing the decisions they make with regard to disaster response planning.

Research in the geography of hazards – in addition to the sociology of disaster studies – has gained greater attention among academics, professionals, and policy makers in the United States, largely due to the succession of national and global disaster events that have occurred within the last twenty-five years. Recent articles identify several natural hazards which affect the Portland region, including (but not limited to) severe weather events, landslides, and local earthquake faults (Knapp & Hadley 2012; Booth et al. 2009; Liberty et al. 2003). While advances in GIS, remote sensing technology, and internet media have enabled researchers and emergency managers to analyze hazard and risk information more effectively, a comprehensive analysis of social vulnerability to multiple hazards can further improve local officials' abilities to identify vulnerable communities and prioritize hazard mitigation efforts in the areas of greatest vulnerability.

This paper presents an assessment of hazard exposure and social vulnerability completed in four phases: hazard analysis, exposure analysis, vulnerability analysis, and risk analysis. The hazard analysis used GIS data from federal and state sources to identify the hazard zones of multiple hazards. The exposure analysis involved a comparison between hazard zones and populated areas defined by the U.S. Census Bureau. The vulnerability analysis examined relative degrees of vulnerability determined from multiple social indicators. The risk analysis examined selected communities where areas of high-risk hazard exposure intersected areas of high vulnerability; these areas of intersection were limited in number but represented significant populations.

Study Area

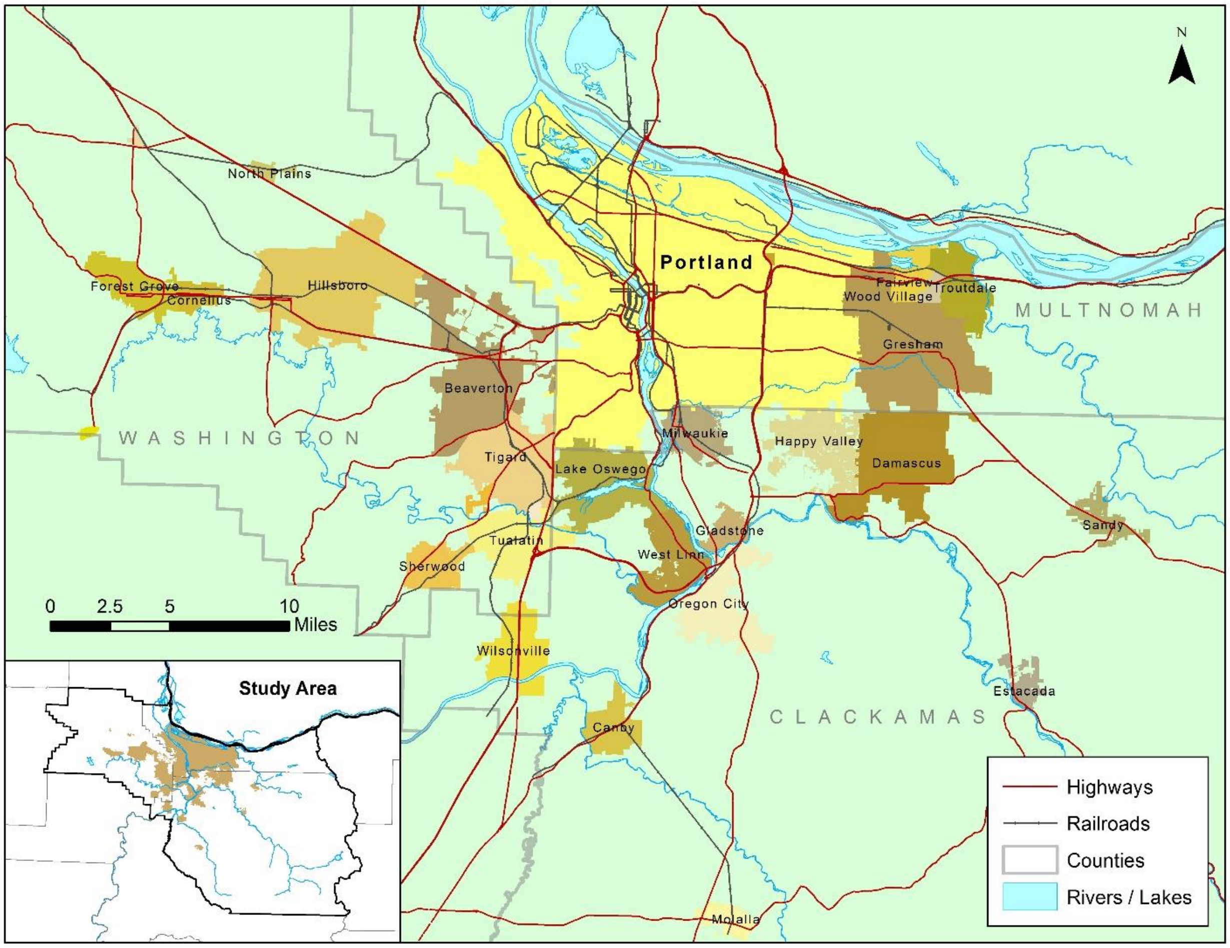


Figure 1. Portland metropolitan area, including major incorporated cities and transportation network. (Sources: ODOT, RLIS)

This study was centered on the Portland Metropolitan Statistical Area (MSA) as defined by the U.S. Census Bureau. While the Portland MSA officially contains six counties in Oregon and Washington, only three of the counties in Oregon – Multnomah, Washington, and Clackamas – were included in the study (Figure 1). The populations of all three of these counties are more than 80% urban, which is above the national average (U.S. Census Bureau 2013), and they share a common emergency planning jurisdiction by being in the same state. This study area was home to approximately 1.64 million people as of the 2010 Census. As a major U.S. metropolitan area and regional industrial and transportation center, Portland is particularly vulnerable to the impacts of potential disaster events. With a dense population and high level of economic development, each of the county governments in the region (plus the larger municipal governments) require a comprehensive response plan and emergency management office in order to assess natural hazards and prepare for possible disasters (Portland Bureau of Emergency Management 2013, Clackamas County Emergency Management 2011, Emergency Management Cooperative of Washington County 2011, Multnomah County Office of Emergency Management 2002).

The physical geography of the Portland region lends itself to a variety of natural hazards (Figure 2). Some have been known to the local population prior to Anglo-American settlement, while others have only been observed or discovered within recent decades. Some of Portland's

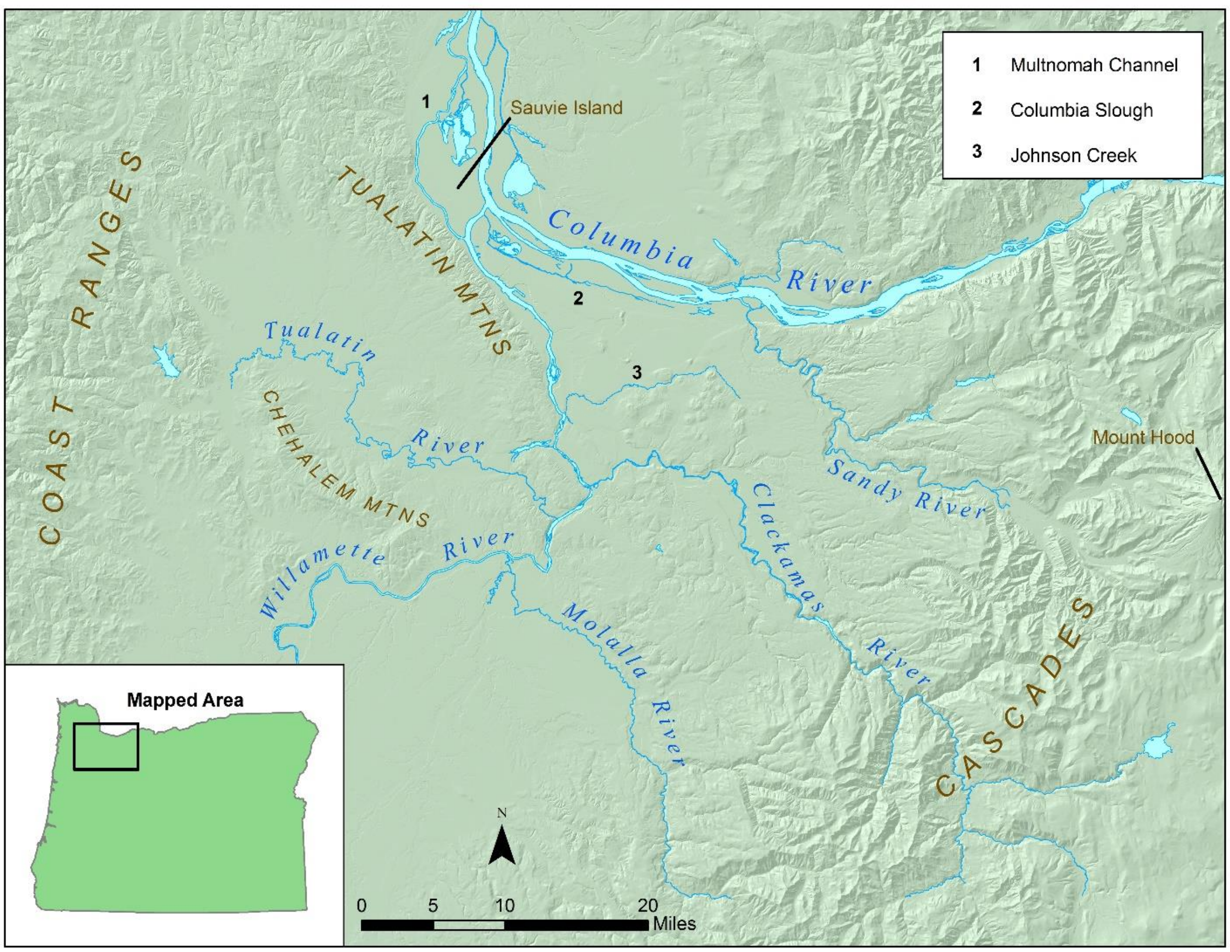


Figure 2. Topography of Portland metropolitan region. (Source: RLIS)

most recognizable natural landmarks are often the source of hazards as well, such as the Willamette and Columbia rivers and the volcanic Cascade peaks of Mount Hood and Mount St. Helens. The history of local flood events is well documented (Dressbeck 2006, Maben 2000), while landslides have also been frequent and familiar to the area (Oregon Department of Geology and Mineral Industries 2008). While wildfires have been more common in rural areas in the Pacific Northwest, a few of these have occurred near communities within the study area, including two wildfires occurring this year (Bailey 2014, Harbarger 2014). The Portland region has witnessed a significant number of disaster events since the mid-20th century, including the 1948 Vanport flood, the 1962 Columbus Day storm, the 1980 Mount St. Helens eruption, and the 1996 Willamette Valley flood.

While the region does not have a prominent history of earthquake events, it is far from immune to them. In 1993, a 5.6-magnitude earthquake struck in rural Clackamas County (about 40 miles south of Portland), causing substantial damage in the surrounding area (Madin et al. 1993). More recently, a team of geologists discovered a series of three potentially active faults within the city limits of Portland (Liberty et al. 2003). Numerous studies have examined the seismic activity and history of the Cascadia subduction zone (Miller et al. 2002, Satake et al. 1996), which could generate an earthquake strong enough to impact the entire Portland region and the western portions of Oregon and Washington.

In addition to the natural hazards existent in the region, there is increasing attention given to some technological or industrial hazards and the risks they pose to the population. Portland has long been a transportation hub for national highway and railroad networks. In particular, there has been an increasing amount of railroad traffic transporting oil from North Dakota to port terminals in the greater Portland region and elsewhere in the United States; along with this increase in traffic has come a sharp rise in the number of accidents involving oil trains, including three incidents within the past year. (A major explosion in the Canadian province of Quebec killed 47 people.) The spike in rail traffic – and a lack of regulatory efforts to keep pace with it – represent a growing hazard to many communities in the vicinity of major rail lines and terminals in the region (Davis 2014).

Literature Review

One of the leading researchers in the geography of environmental hazards and social vulnerability, Cutter (1996) introduced the *hazards of place* conceptual model as an attempt to integrate the various factors of biophysical vulnerability (from either natural or technological hazards) and social vulnerability (based on social or economic conditions) that are present in a given location or region. The integration of these factors allows a more comprehensive analysis of *place vulnerability*. The primary advantage of this conceptual model to researchers and professionals in the hazards field is its flexibility in incorporating multiple hazards and/or socioeconomic characteristics into an overall assessment of risk and vulnerability.

This model was applied (Cutter et al. 2000) to a case study in Georgetown County, South Carolina, a location familiar to the researchers and containing a variety of hazards and population groups. One of the objectives of the authors' research was to highlight the idea that the vulnerability of a given population depends on additional factors beyond its proximity to a hazard. In their study, the authors identified multiple hazards from several federal and state data sources, and relative annual frequencies were calculated from the number of occurrences within the existing record of a particular hazard. Risk zones for natural hazards were delineated based on either existing spatial data where available (e.g. FEMA flood data) or data derived from computer models (e.g. storm surge and wind data from the National Hurricane Center). Hazardous chemical release zones from fixed sites, highways, and railroads were delineated from U.S. Department of Transportation guidelines on minimum safe distances for such hazard events. In order to measure social vulnerability, the authors used demographic data from the 1990 U.S. Census block-level statistics. The key demographic characteristics used to determine vulnerable populations included the following: age (under 18 or over 65), race/ethnicity (non-white), gender (female), wealth/poverty (mean home value), and structural vulnerability (mobile home residents).

Subsequent studies have applied the methods used by Cutter et al. (2000) to other locations in the U.S. and at different scales. Schmidtlein et al. (2008) examined the sensitivity of Cutter et al.'s social vulnerability approach to changes in the scale applied, the variables used, and the geographical context of alternate study areas (specifically: Charleston, New Orleans, and Los Angeles), and they found that the results were relatively consistent in producing an overall vulnerability profile. Other studies have utilized a similar methodology to analyze social vulnerability for different metropolitan areas, though the results were integrated with the exposure of either a single hazard (Burton & Cutter 2008; Collins et al. 2009) or a pair of related hazards (Chakraborty et al. 2005). Each of these studies conducted their analysis for one or more counties at the census block group level, except for the study by Burton & Cutter (2008), which was done at the census tract level.

In a comparable study, Chen et al. (2004) attempted to identify and illustrate areas at risk of natural hazards as part of a four-step approach: hazard analysis (measuring hazard characteristics), exposure analysis (mapping elements at risk), vulnerability analysis (determining the degree of susceptibility), and risk analysis (synthesizing these analyses). Their study examined the risks of hailstorms and earthquakes in the metropolitan region of Sydney, Australia, as measured by the number of homes damaged and their estimated insured values. Two units of area were used for exposure analysis (postcode areas and census collection districts) for the purpose of comparing scales of resolution in relation to a hazard analysis (completed at a raster grid level). The authors found a significant difference in the results of their exposure analysis between the areal units with regard to the fine-scale hazard zones produced by hailstorms, with a smaller difference observed in the case of broad-scale earthquake hazards. The study lacked a multiple-indicator vulnerability analysis which could have addressed variations in building density or demographic indicators.

The objective of this study was to undertake a place-based vulnerability analysis of the Portland metropolitan region which integrated hazard risk exposure and social vulnerability indicators, in order to create a GIS that would facilitate the identification of the areas at the greatest risk of disaster losses. While several municipal governments in the metropolitan area have completed some form of hazard risk analysis (addressing multiple hazards), no publications have been found to date that address social vulnerability for any of the counties or cities in the region. The methodology of this study has largely been adapted from Cutter et al.'s (2000) case study conducted in South Carolina, while it also borrows the four-step approach described in Chen et al.'s (2004) study conducted in Sydney. An attempt has been made to determine whether the areas at greatest risk of losses are more closely associated with demographic characteristics than with hazard exposure, particularly where there are high numbers of vulnerable social groups. A qualitative description has been provided of the overall vulnerability of the metropolitan region and of those communities at the greatest risk of losses.

Methodology

In order to conduct a hazard analysis of the Portland metropolitan region, hazards were selected which exemplify potentially intensive events, or events of a higher magnitude and lower frequency than the regional norm (such as floods or wildfires), as opposed to pervasive events (such as heat waves or rising sea-levels). Hazards were also considered for analysis based on the exhibition of discrete spatial patterns which can be clearly, if not always precisely, measured and illustrated. Four natural hazards were selected for analysis which are relatively common to the region: floods, wildfires, landslides, and earthquakes. An additional hazard of a technological nature – oil train accidents – was included in the analysis as well. Information was directly obtained or inferred from existing federal and state GIS databases for the purpose of indicating the relative probability and spatial distribution of each of these hazards.

Flood hazard data were derived from the Federal Emergency Management Agency (FEMA) preliminary flood hazard data. Most of the data were acquired directly from FEMA's National Flood Hazard Layer (NFHL) GIS web service; these data were supplemented with FEMA data obtained through the Oregon Department of Environmental Quality's Incident Response Information System (OR-IRIS) database. Wildfire hazard data were derived from the Oregon Department of Forestry's Communities at Risk Assessment, which has made its data available via the Oregon Spatial Data Library. Landslide susceptibility data were obtained from the Oregon Department of Geology and Mineral Industries (DOGAMI), which was also the source of earthquake liquefaction hazard data. Oil train hazard data were developed from railroad data produced by the Oregon Department of Transportation, also made available via the Oregon Spatial Data Library. Once all the necessary hazard data was acquired, hazard zones were delineated and assigned relative degrees of probability.

Flood hazard zones were the simplest to identify, as FEMA defines two primary flood zones by their rate of occurrence: a 1-percent-annual-chance (or 100-year) flood inundation zone, and a 0.2-percent-annual-chance (or 500-year) flood inundation zone. A secondary flood zone of reduced risk due to levee construction is also identified. At the time of writing, the data set published for Washington County was incomplete (Federal Emergency Management Agency 2014), covering only the eastern half of the county. This necessitated the addition of FEMA data from OR-IRIS (Oregon Department of Environmental Quality 2014), which was available for the entire state of Oregon but included 100-year flood zones only. The 100-year, 500-year, and reduced flood zones have been categorized as high, medium, and low risk zones, respectively.

The wildfire hazard data set was originally published (Oregon Geospatial Enterprise Office 2014) in a raster format and then converted into a vector format, in order to illustrate clearly defined hazard zones. Several generalization techniques were applied to the hazard data during the conversion process, mainly to remove areas too small (<10,000 sq. ft.) to provide a meaningful analysis. Wildfire hazard ratings were assigned by the Oregon Department of Forestry (ODF) within a range of five levels of risk: 0 (no risk), 1 (low risk), 2 (medium risk), 3 (high risk), and 4 (very high risk) (Oregon Department of Forestry, 2006). The data were also compared with aerial imagery (via Google Maps) in order to identify urban green areas, such as municipal parks and golf courses; these were frequently categorized as "medium risk" based on ODF's criteria, though they are unlikely to pose any realistic threat of a wildfire. For this study area, there are no zones identified as low risk, therefore only the three remaining levels of risk have been shown.

Landslide susceptibility data were also published in a raster format (Oregon Department of Geology and Mineral Industries 2013), which was converted and generalized in a manner similar to the wildfire hazard data. DOGAMI had originally utilized a ten-level classification scheme of landslide susceptibility, which was based on geology type and slope angle (Table 1). This scheme was reclassified into four categories as follows: no risk, low risk (levels I-IV), medium risk (levels V-VII), and high risk (levels VIII-X). Earthquake liquefaction susceptibility data was published (Oregon Department of Geology and Mineral Industries 2013) in vector format and organized into five levels of risk. Liquefaction susceptibility published by DOGAMI was chosen over alternative indicators of earthquake hazard (such as predicted ground shaking) due to its relatively discrete spatial distribution within the study area; by comparison, other indicators are evenly spread over the Portland metropolitan region. The focus on liquefaction risk also allows for the consideration of earthquakes produced from either the Cascadia subduction zone or local transform faults, such as the Portland Hills Fault.

In order to delineate hazard zones for oil train accidents – specifically, the hazard of oil tanker car fires or explosions – railroad line and ownership data were acquired from the Oregon

Table 1. Landslide susceptibility of geologic groups.
(Source: Oregon Department of Geology and Mineral Industries, 2013)

Geologic Group	Slope Angle (degrees)					
	0-10	10-15	15-20	20-30	30-40	>40
Dry Terrain (groundwater is below level of sliding)						
Strongly cemented rocks (*crystalline rocks or well-cemented sandstone*)	none	none	I	II	IV	VI
Weakly cemented rocks and soils (*sandy soils or poorly cemented sandstone*)	none	III	IV	V	VI	VII
Argillaceous rocks (*shales, clay soils, non-compacted fills, existing landslides*)	V	VI	VII	IX	IX	IX
Wet Terrain (groundwater level is at/near ground surface)						
Strongly cemented rocks (*crystalline rocks or well-cemented sandstone*)	none	III	IV	VI	VIII	VIII
Weakly cemented rocks and soils (*sandy soils or poorly cemented sandstone*)	V	VIII	IX	IX	IX	X
Argillaceous rocks (*shales, clay soils, non-compacted fills, existing landslides*)	VII	IX	X	X	X	X

Department of Transportation via the Oregon Spatial Data Library (Oregon Geospatial Enterprise Office 2014). The major railroad firms responsible for the vast bulk of oil transport through the region have been identified in recent news articles (Davis 2014), and railroad ownership data was reviewed in order to determine which rail lines were used for oil transport. Buffer zones were defined around each of these rail lines, with a half-mile radius and a one-mile radius; these distance were based on the recommended evacuation distances established by the U.S. Department of Transportation for oil tanker car derailments and fires, respectively (U.S. DOT 2012).

An exposure analysis was conducted in order to measure the social vulnerability, or population at risk, to each of the selected hazards in the metropolitan region. This process was completed using data from the 2010 U.S. Census enumerated at the block group level. Five demographic attributes were chosen for analysis: total population, the number of people under 18, the number of people over 65, the number of minority (non-white) residents, and the number of low-income households. These attributes were selected based on a common set of factors which influence social vulnerability, as described by Cutter et al. (2000), such as relative physical abilities, a lack of access to resources and information, limited access to political power. A spatial data set containing the block group polygons was obtained from the Oregon Spatial Data Library (Oregon Geospatial Enterprise Office 2014); the data set included figures for total population, residents under 18, and population counts by race. The remaining demographic data were selected from the Census Bureau's American Community Survey, using the five-year estimates from the 2008-2012 period. Each demographic attribute was normalized by calculating a ratio of a given attribute in each block group to the total number for the three-county study area. The ratio was then divided by the maximum ratio found within the study area in order to produce a vulnerability index (VI) ranging from 0 to 1. Subsequently, all values were summed to provide a composite VI for each block group, which facilitated an overview of social vulnerability for the metropolitan region.

Once the spatial patterns of vulnerable populations were identified, a vulnerability analysis was performed to examine the potential overlap of hazard zones and socially vulnerable communities. The combination of multiple layers of information in spatial analysis falls into a framework of multi-criteria decision making (Malczewski 1999). The layers could be weighted equally or differently based on expert opinions, statistical estimations, or the preferences of decision makers. GIS provides a flexible and efficient information management system for performing different types of multi-criteria decision making. The decision model presented below serves to demonstrate the use of the results of the risk and vulnerability analyses. Risk managers could possibly modify the model to fit the planning and communication needs specific to the communities which they serve.

In this study, block groups were selected interactively in a GIS where they intersected with a hazard zone for each hazard. For flood hazards, hazard zones were relatively constricted, therefore all block groups containing any hazard zone of significant area (greater than 10,000 sq. ft.) were included in the vulnerability analysis. A similar approach was taken with landslide susceptibility zones; however, it should be noted that the hazard analysis produced large zones of "medium" risk which cover the vast majority of the study area (mainly regions of loose soil with minimal slope). Wildfire hazard zones were distributed more broadly across the study area; in this case, only block groups with at least 50% coverage by a wildfire hazard zone were selected for analysis. Earthquake and oil train hazard zones, which covered moderately sized areas, were analyzed in the same manner as wildfire hazard zones.

A comprehensive, quantitative risk analysis for the metropolitan area is problematic, due to variations among each of the hazards in terms of probability, magnitude, and spatial extent. In light of this hindrance, an overall analysis of risk was completed by highlighting the communities where the areas of highest risk from hazards intersected the areas of greatest vulnerability.

Results: Hazard and Exposure Analysis

In all, a total of six GIS data sets were acquired from federal or state sources and utilized for this study. Two data sets (landslide susceptibility and earthquake liquefaction susceptibility) were purchased from DOGAMI in CD-ROM format; all others were downloaded from their respective sources at no cost. All GIS layers were projected into the Oregon Statewide Lambert projection on the 1983 North American datum. For the vulnerability analysis, attributes fields were added to the original census block group data set in order to determine vulnerability index values based on social indicators; these values were calculated according to the methodology described earlier. All results were portrayed in a series of maps, with additional data presented in tables when practical.

As one would presume, flood hazard zones are concentrated along the main rivers and streams within the metropolitan area (Figure 3). The largest floodplains are located adjacent to the Columbia River and its channels (including the Columbia Slough and Multnomah Channel) and in the Tualatin Valley, along the Tualatin River and its many tributary creeks. Other significant areas of flood hazard are situated along the Molalla River and near sections of the Willamette River. Despite its size and length, the portion of the Willamette River within the study area has a relatively narrow floodplain associated with it, where it is constrained by the hilly terrain between the Tualatin Mountains (or the "West Hills") and the buttes to the east. Smaller floodplains can be found along the Sandy River, Clackamas River, and Johnson Creek. The areas at greatest risk of flooding – those within the 100-year floodplain – include the Tualatin River, the Molalla River, the Sandy River delta, and the junction of the Willamette and

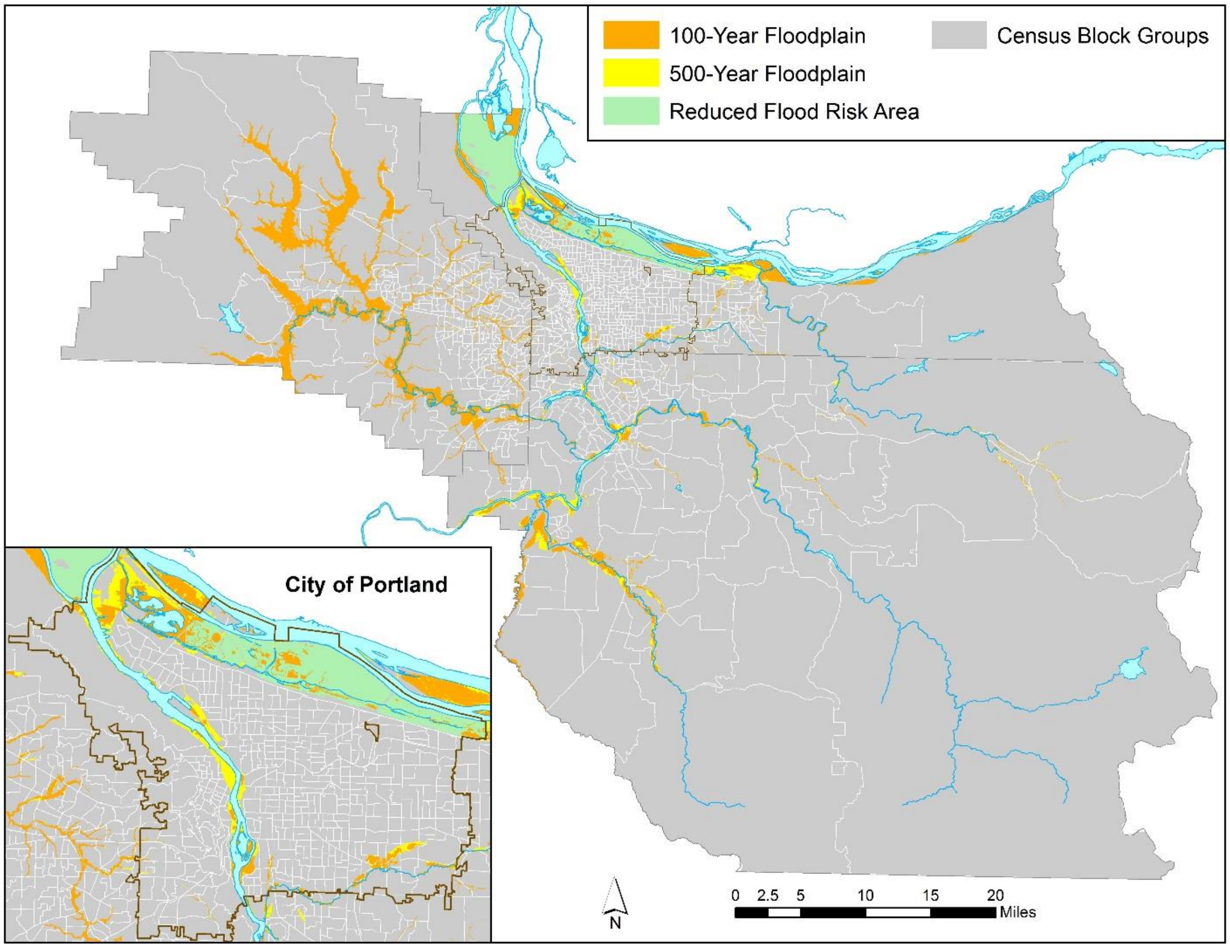


Figure 3. Flood hazard zones. (Sources: Census Bureau, FEMA, Oregon IRIS, RLIS)

Clackamas rivers. Sauvie Island and the Columbia Slough area are designated by FEMA as having a reduced risk of flooding, due to an existing system of levees; in the event of a failure of one of these levees, the risk of flooding can rise substantially.

Many residential communities in the metropolitan area lie at least partially within a floodplain. In the city of Portland, much of the Downtown, Pearl, and Southwest Waterfront districts lie in a flood hazard zone, along with the neighborhoods of Hayden Island, Sellwood, and Lents. Suburban communities at risk include central Beaverton, Tigard, Tualatin, Wilsonville, Gladstone, portions of Oregon City, and most of the Canby area. The vulnerability analysis identified 303 census block groups (29% of all block groups in the study area) which contained at least one flood hazard zone of 10,000 sq. ft. or more. The population living in a floodplain has been estimated by calculating the proportion of each block group area covered by a hazard zone, multiplying the proportional area by the block group population, and then totaling the results. This method provides an estimated figure of 82,637 people living in a floodplain.

Wildfire hazard zones typically coincide with the regions of elevated and forested terrain within the study area (Figure 4), most of which are rural and undeveloped. The largest hazard zones are found in the Tualatin Mountains, the east slope of the Coast Range (western Washington County), and the Cascade foothills in eastern Clackamas and Multnomah counties. Other hazard zones include the Chehalem Mountains (a range of hills in southern Washington County), the buttes southeast of Portland, and the Columbia River Gorge. The vast majority of wildfire hazard zones are rated by the ODF as medium risk, though there are small stretches of high- to very-high-risk zones in the upper elevations of the Cascades.

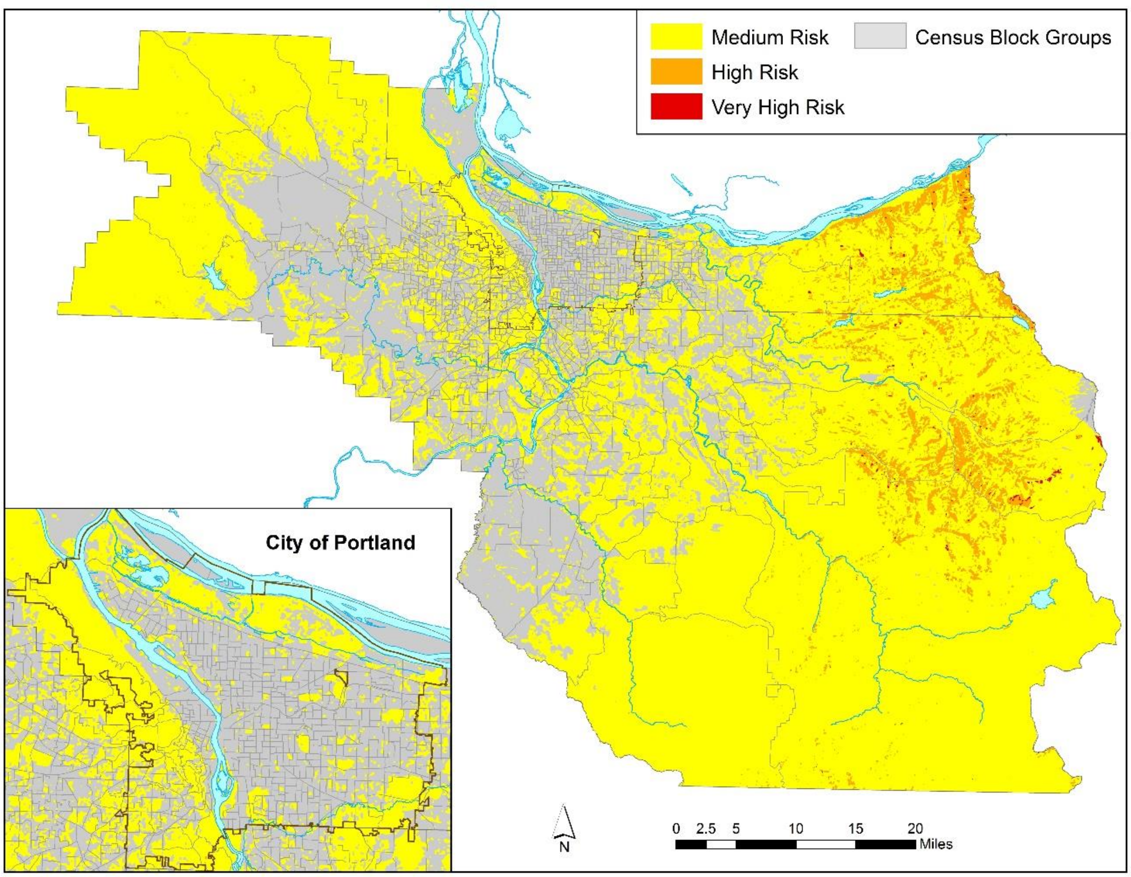


Figure 4. Wildfire hazard zones. (Sources: Census Bureau, ODF, RLIS)

There are only a handful of suburban and rural communities which are situated in or near wildfire hazard zones. The most notable of these are Happy Valley, Estacada, Sandy, and Mount Hood Village. In addition, a few Portland neighborhoods are located in hazard zones, mostly in the West Hills area; these include Southwest Hills, Sylvan Highlands, Northwest Heights, Forest Park (synonymous with the urban reserve), and Pleasant Valley (bounded by the eastern buttes). The outskirts of Oregon City, mostly composed of densely wooded canyons and bluffs, also qualify as a significant hazard area. Altogether there are 95 block groups that contain at least 50% coverage of a wildfire hazard zone, and these block groups represent an estimated 120,660 residents, though most of these are dispersed throughout the northwestern and southeastern edges of the metropolitan area.

Hazard zones of landslide susceptibility are most frequently found in areas of varied terrain (Figure 5), due to the correlation between landslide risk and the degree of slope and/or geologic stability of a given location. Most of these hazard zones exist in the Tualatin Mountains, the Coast Range, the Cascades, and the Columbia River Gorge. Smaller hazard zones are located near the Chehalem Mountains, the buttes southeast of Portland (including Rocky Butte and Mount Tabor), the bluffs along the Willamette River, and the Sandy River valley. The hazard analysis produced large zones of "medium" landslide risk – as has been mentioned previously – due to the widespread extent of flat expanses of loose alluvium soil within the study area (see Table 1).

The zones of landslide risk represent near-total coverage of the study area, particularly the developed portions, which limits the ability to present a meaningful vulnerability analysis. In any case, a substantial number of communities are placed in or near zones of high landslide susceptibility, distributed across the metropolitan area. Within the city of Portland, these include

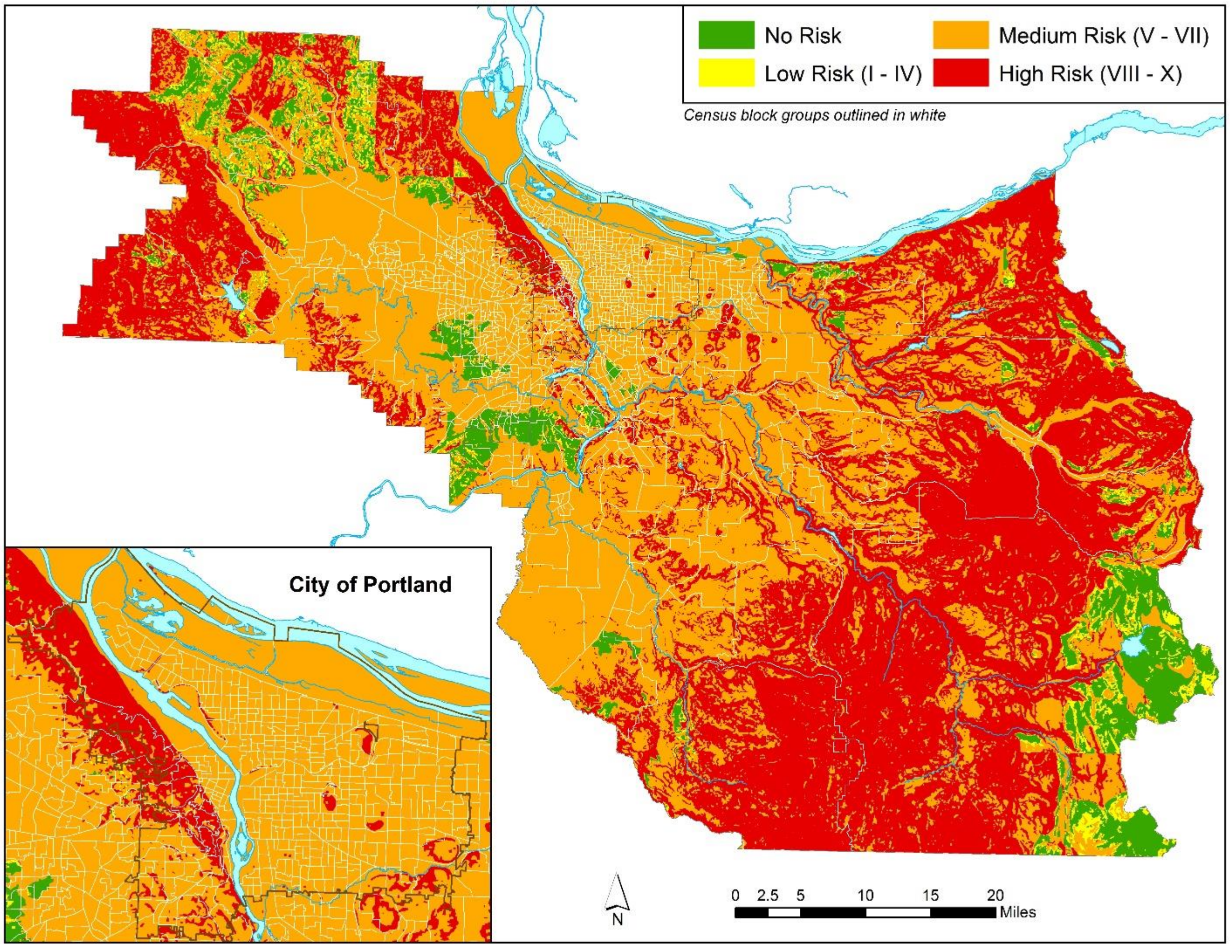


Figure 5. Landslide susceptibility zones. (Sources: Census Bureau, DOGAMI, RLIS)

most of the neighborhoods in the West Hills, plus the neighborhoods of University Park, Overlook, Mount Tabor, and Pleasant Valley. Suburban communities at risk include Lake Oswego, West Linn, Oregon City, Happy Valley, Troutdale, and the southern portion of Gresham. The vulnerability analysis revealed 214 block groups which intersected *high-risk* landslide susceptibility hazard zones, with an estimated 95,615 residents at risk.

An analysis of earthquake liquefaction susceptibility revealed distinct patterns within the study area. Zones of liquefaction susceptibility are concentrated in regions of loose alluvium with relatively high groundwater tables (Figure 6). Such regions exist along the Columbia River floodplain (including Sauvie Island), the banks of the Willamette River (especially the east bank), the Tualatin Valley, the Clackamas River valley, and the northern edge of the Willamette

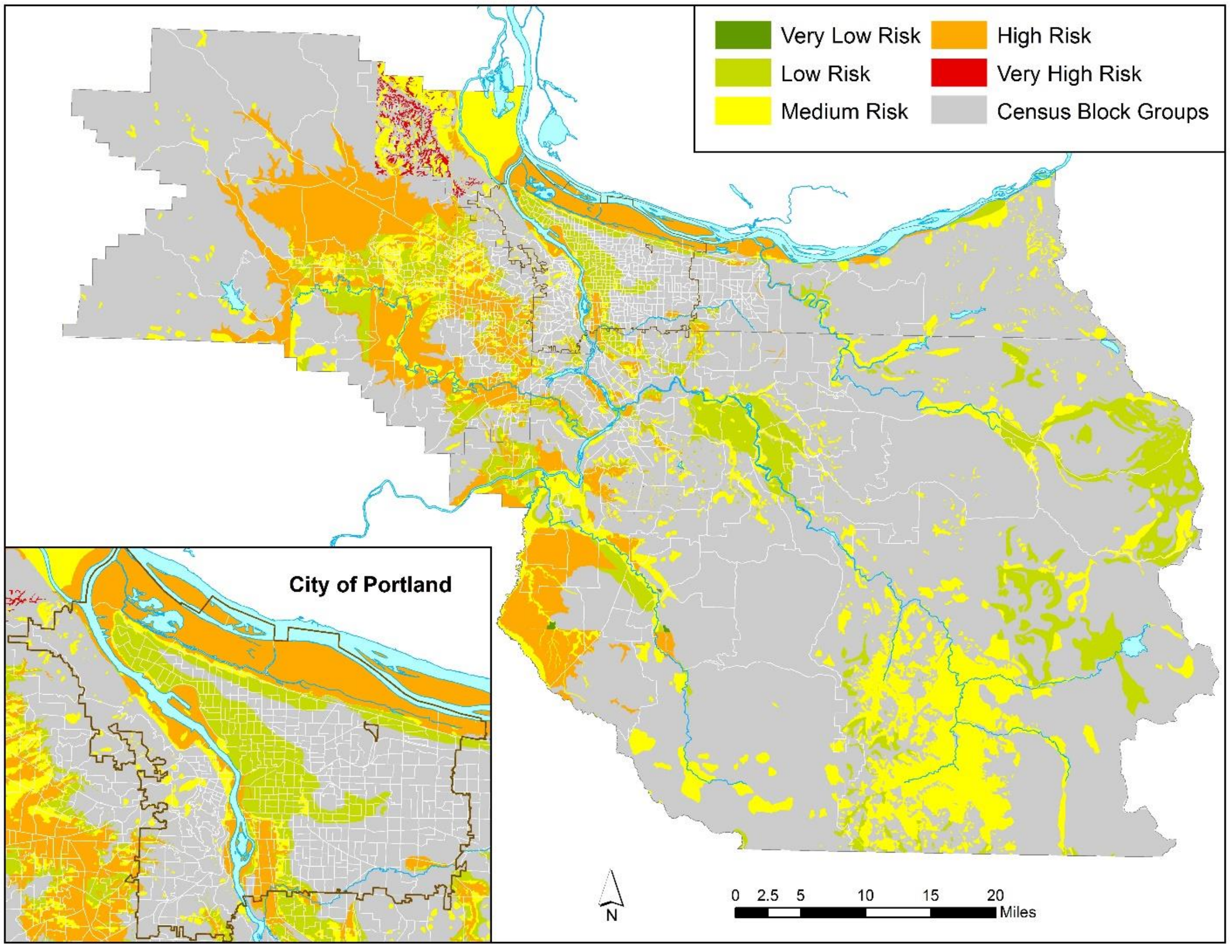


Figure 6. Earthquake liquefaction susceptibility zones. (Sources: Census Bureau, DOGAMI, RLIS)

Valley in western Clackamas County. Curiously, there is also a cluster of hazard zones in the upper Tualatin Mountains categorized as "very high" risk, though it is unclear from the data to which factor(s) this level of risk can be attributed.

A large portion of the developed metropolitan area can be found within liquefaction-susceptible zones. A total of 583 block groups overlap an earthquake liquefaction hazard zone (>50% coverage); these constitute less than half of the study area, but contain 749,873 residents, or about 45% of the area's population. For the city of Portland, the neighborhoods at greatest risk include Downtown/Old Town/Pearl District, South Waterfront, Corbett-Terwilliger, Brooklyn, and Sellwood. Many more neighborhoods are at moderate or low risk of liquefaction, including most of North Portland and the inner portions of Northeast and Southeast Portland. Suburban communities at high risk of liquefaction include the cities of Tualatin, Tigard, Beaverton, Aloha, Forest Grove, Milwaukie, Canby, and Fairview.

Hazard zones for oil train accidents were derived from railroad data based on the main routes utilized for oil transport (Figure 7). The major firms responsible for transporting oil through the Portland metropolitan area are BNSF and Union Pacific; BNSF operates its oil trains via two routes on either side of the Columbia Gorge, while Union Pacific operates a third route through the Willamette Valley. Additionally, the Portland & Western Railroad company transports oil from rail terminals in Portland to the Port Westward shipping terminal near the town of Clatskanie, about 60 miles north of Portland on the Columbia River. Two buffer zones were created from these oil train routes: a half-mile radius zone, from the recommended

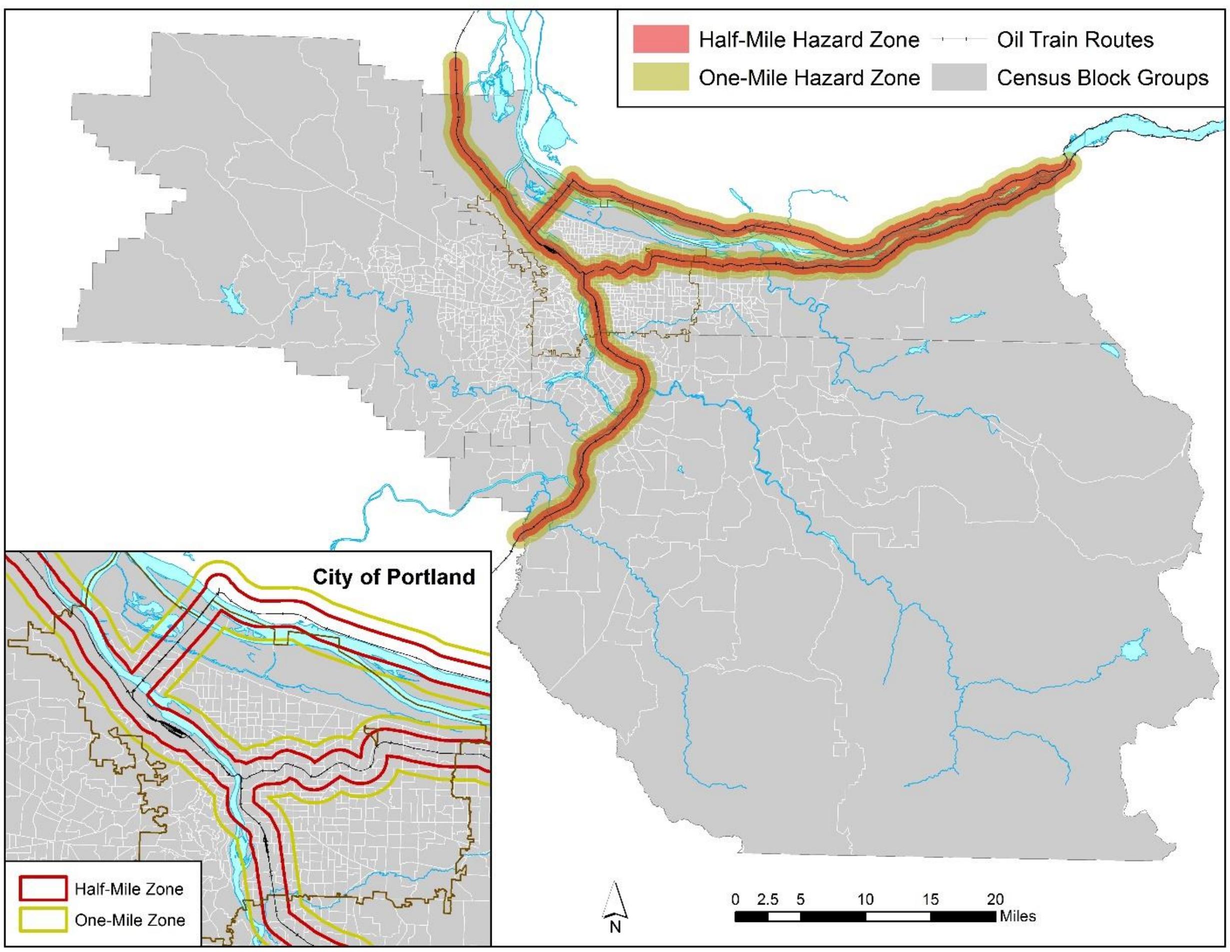


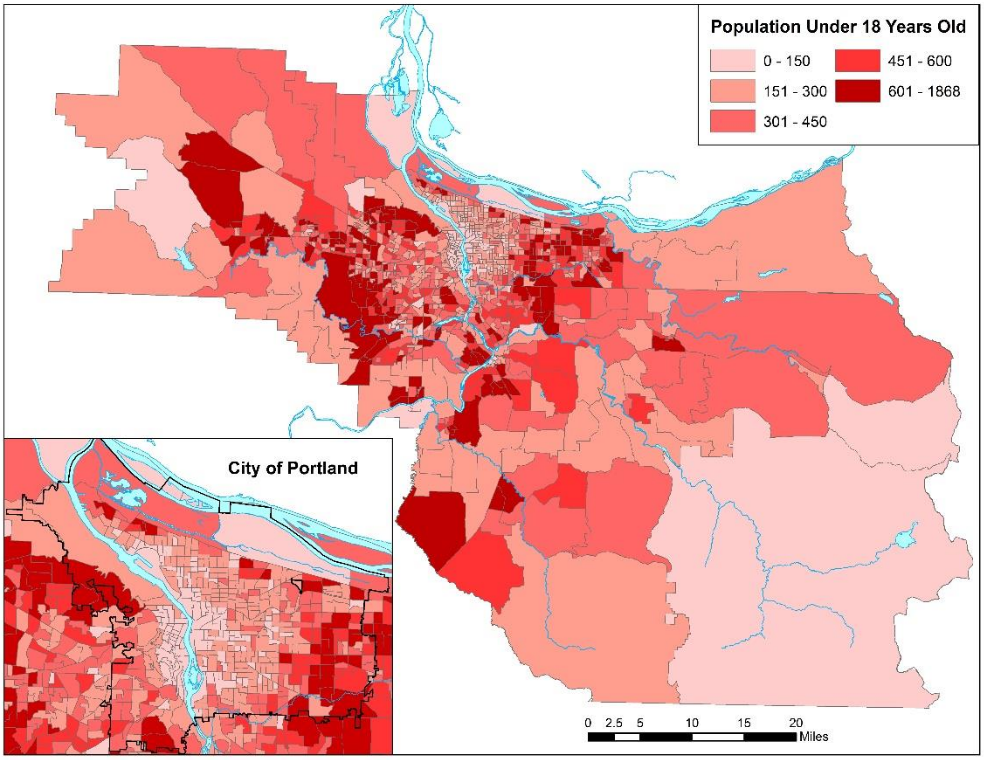
Figure 7. Oil train accident hazard zones. (Sources: Census Bureau, ODOT, RLIS)

evacuation distance for a tanker car derailment (and possible spill), and a one-mile radius zone, from the evacuation distance for a tanker car fire. The resulting hazard zones overlap 264 block groups in the study area, with an estimated 327,460 residents, the majority of which are found in the city of Portland. The neighborhoods closest to oil train routes – and at the greatest risk of exposure to oil train accidents – include Old Town/Pearl District, St. Johns, Portsmouth, Hollywood, Laurelhurst, the Central Eastside, Brooklyn, and Sellwood. Beyond the city limits of Portland, the communities of Fairview, Troutdale, Milwaukie, Clackamas, and Oregon City also lie within the hazard zones of oil trains.

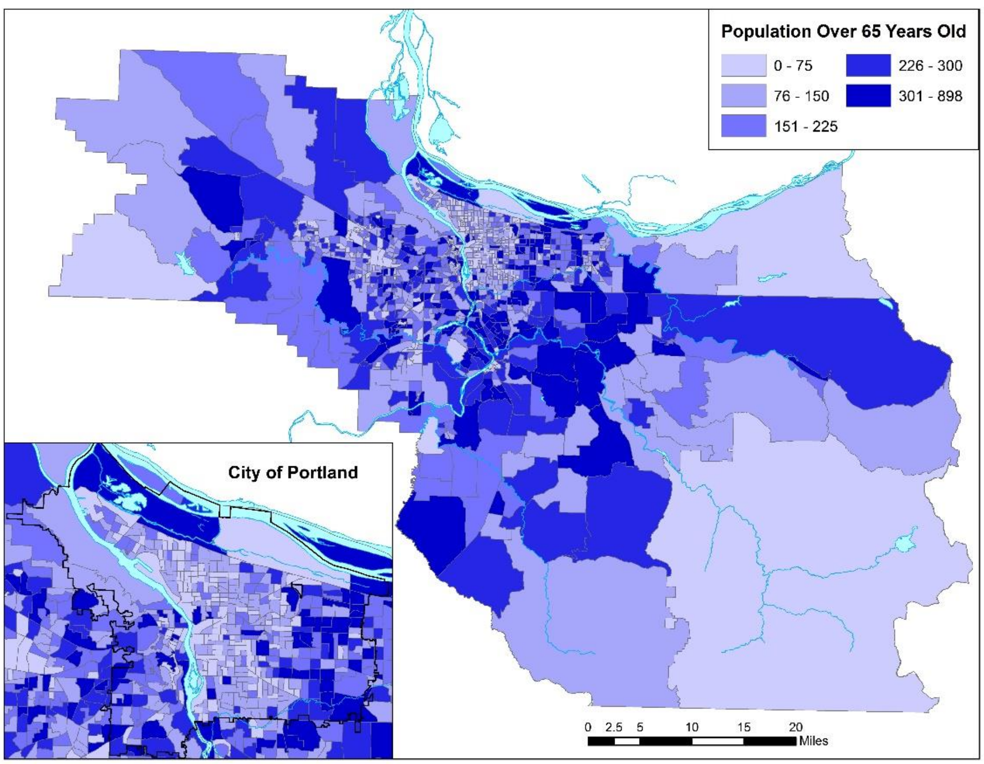
Results: Vulnerability and Risk Analysis

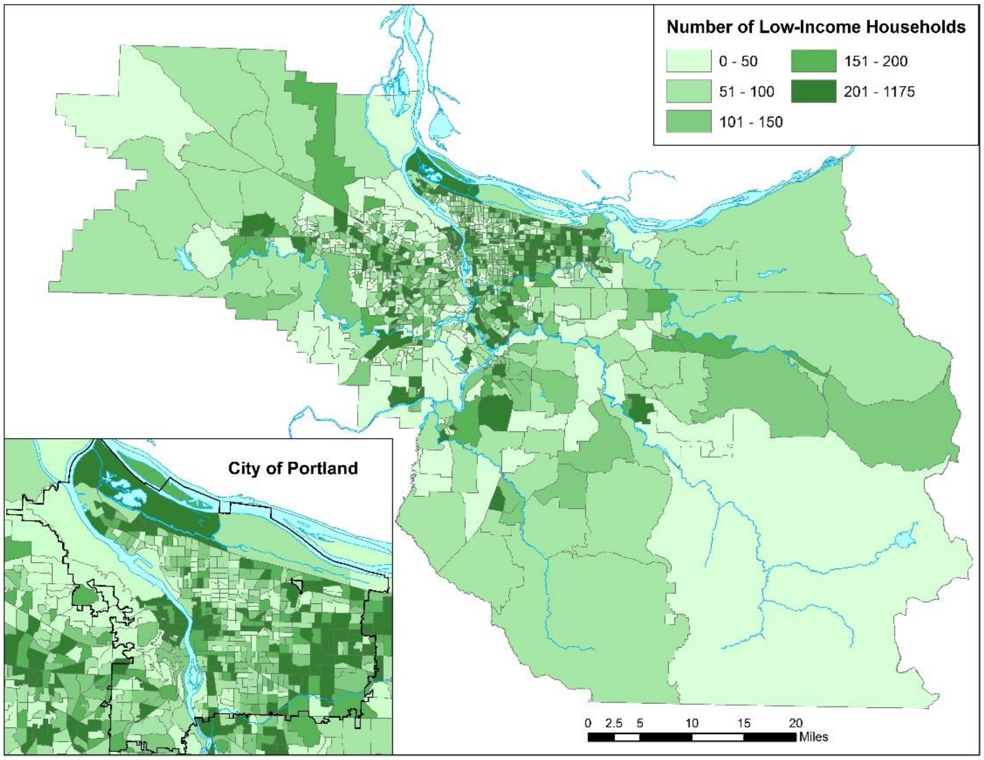
Patterns of social vulnerability within the Portland metropolitan area vary by demographic group. In the case of the two age-related categories – people under 18 years old and people over 65 years old – youth and senior populations exhibit a somewhat dispersed pattern across the study area (Figures 8 and 9). However, based on their vulnerability indices, minor concentrations of these groups can be observed in the suburban regions of eastern Portland, central Multnomah County, eastern and central Washington County, and northwestern Clackamas County, with a relative dearth in Portland's central city. (Youth populations appear to be more clustered than senior populations.) In regard to low-income households, the block groups with the highest numbers are found on the northern and eastern outskirts of Portland proper, and in the cities of Gresham, Beaverton, Forest Grove, and the suburbs of northwestern Clackamas County (Figure 10). There are also significant numbers of low-income households in Portland's city center, though these figures are likely to be correlated with the greater overall populations of those block groups. Racial minority populations reveal the most clustered patterns of the demographic groups analyzed (Figure 11). Distinct concentrations of minorities are located along the northern edge of Portland, in East Portland, in Gresham, and in portions of Beaverton and Hillsboro.

Each vulnerability index value was summed to determine a composite vulnerability index (VI) for all block groups. The resulting spatial pattern indicates that the greatest number of block groups with the highest levels of vulnerability (the top 10% of composite VI values) exist in central Multnomah County, northwestern Clackamas County, and central Washington County (Figure 12). These regions include the neighborhoods of East Portland, the cities of Gresham, Happy Valley, Wilsonville, and Forest Grove, the communities of Cedar Mill and Bethany, and

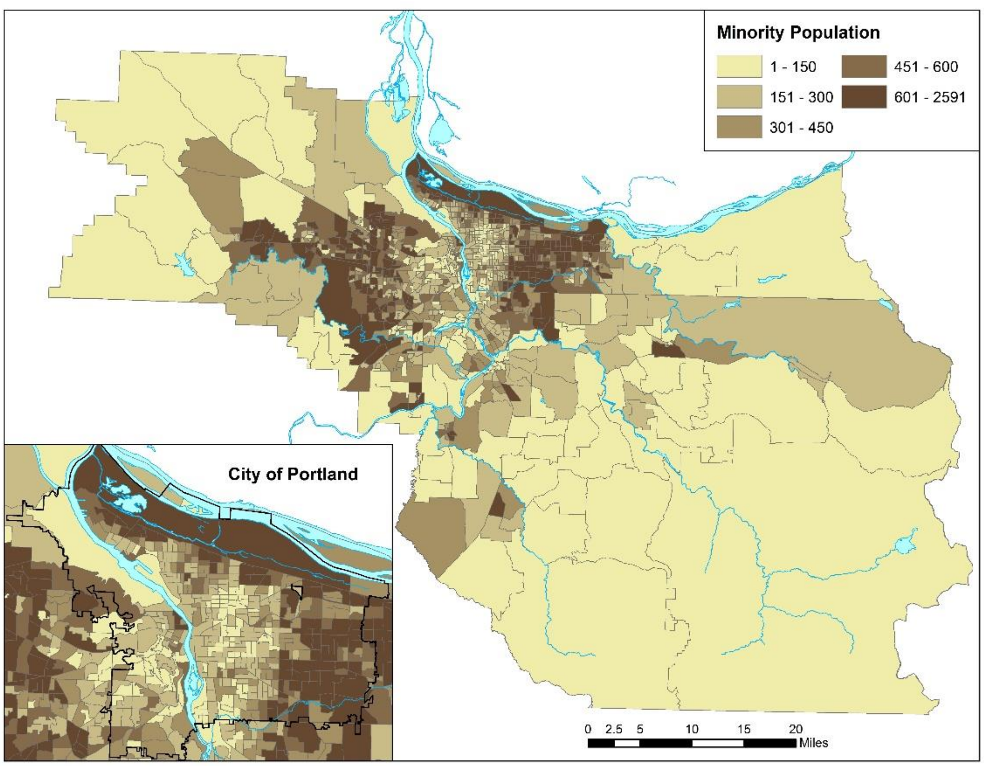


Figures 8 and 9. Patterns of youth populations (above) and senior populations (below).
(Sources: Census Bureau, RLIS)





Figures 10 and 11. Patterns of low-income households (above) and racial minority populations (below). (Sources: Census Bureau, RLIS)



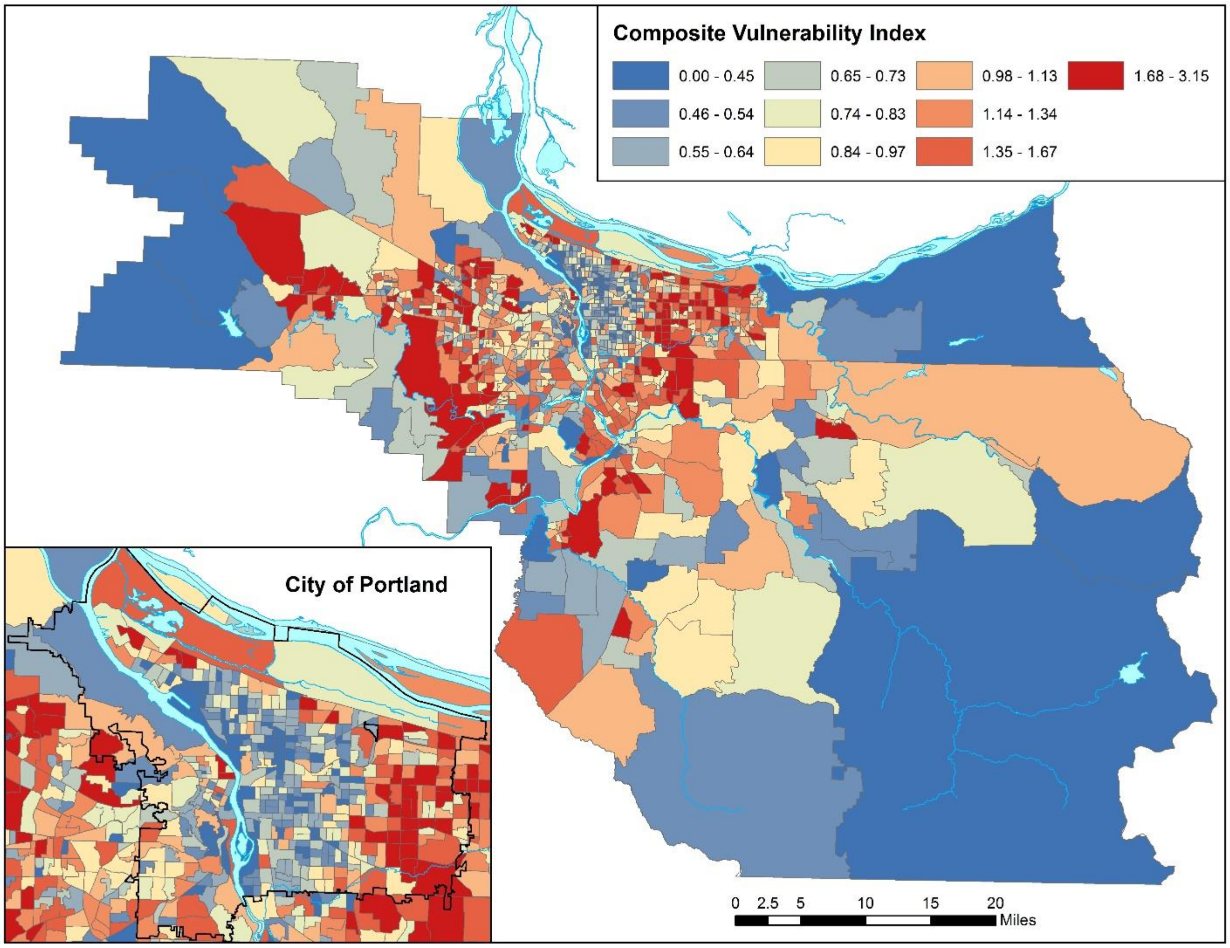


Figure 12. Composite vulnerability indices for the metropolitan area. (Sources: Census Bureau, RLIS)

portions of Beaverton and Hillsboro. Other pockets of high vulnerability are found in Portland's Old Town and Pearl districts, the neighborhoods of Kenton and Cully, the southern edge of Oregon City, and the western edges of Tualatin and Tigard.

The pattern of composite vulnerability was compared with the results of each hazard and exposure analysis (see Table 2 and Figures 13-17). Population totals were calculated for those block groups within a hazard zone *and* with a composite VI among the top 10% of all block groups. Among those block groups that are located within a floodplain, thirteen of them have a high composite VI; eleven of those are within the 100-year floodplain (the zone of highest risk), representing a total of 35,402 residents. Only six of the block groups in a wildfire hazard zone have a high composite VI, and all of these are in zones of medium risk. There are five block

Table 2. Communities with the highest composite VI scores exposed to hazards.

Hazard Type	**Risk Exposure**	**Block Groups At Risk**	**Population At Risk (est.)**	**Communities At Risk** (***Portland neighborhoods in italics***)
Flood	High	11	35,402	Cornelius, Forest Grove, Tualatin *Pleasant Valley*
	Medium	2	6,572	*Old Town, Pearl*
Wildfire	High	N/A	N/A	N/A
	Medium	6	23,777	Happy Valley, West Linn *Northwest Heights, Pleasant Valley*
Landslide	High	5	20,140	Happy Valley *Northwest Heights, Pleasant Valley*
	Medium	*	*	*
Earthquake Liquefaction	High	18	55,651	Beaverton, Cornelius, Fairview, Forest Grove, Wood Village *Old Town, Pearl*
	Medium	41	128,910	Aloha, Beaverton, Bethany, Canby, Cornelius, Happy Valley, Hillsboro, Milwaukie, Oregon City, Sherwood, Troutdale, Wilsonville *Argay, Cully, Kenton, Pleasant Valley, St. Johns, Wilkes*
Oil train spills / fires	High	10	28,653	Canby, Fairview, Milwaukie, Troutdale, Wood Village *Old Town, Parkrose, Pearl, Wilkes*
	Medium	5	14,664	Gresham *Argay, Portsmouth*

* Medium-risk landslide hazard zones excluded from analysis.

groups with a high composite VI which overlap high-risk landslide hazard zones, with a total of 20,140 residents represented. The greatest number of highly-vulnerable block groups are found within earthquake liquefaction hazard zones; there are 59 block groups within these zones that have a composite VI among the top 10%, and 18 of those lie within high-risk liquefaction zones, containing a population of 55,651. Oil train accident hazard zones cover fifteen highly-vulnerable block groups, ten of which fall within the half-mile evacuation zone (with a total of 28,653 residents).

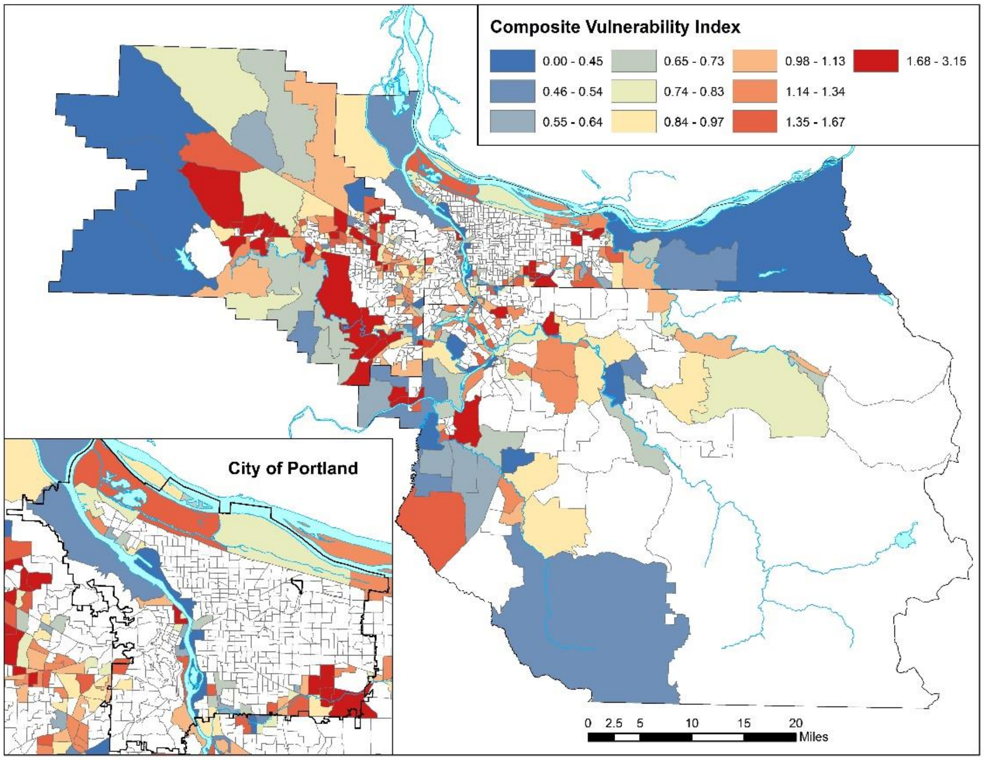


Figure 13. Vulnerability of block groups exposed to flood hazard zones. (Sources: Census Bureau, RLIS)

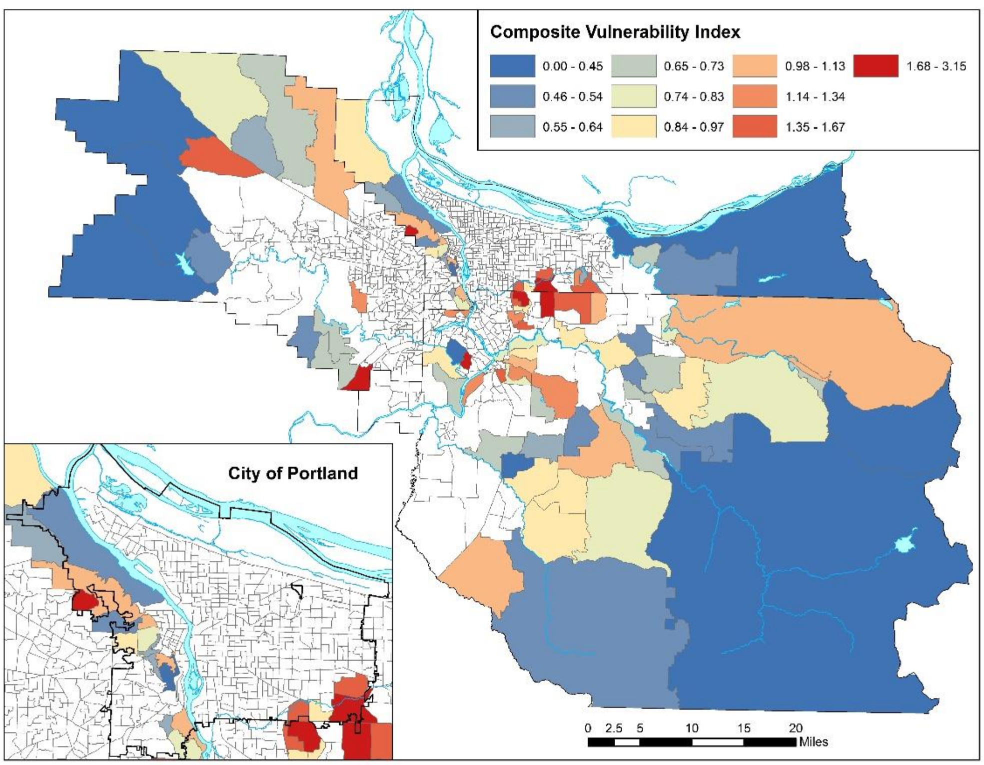


Figure 14. Vulnerability of block groups exposed to wildfire hazard zones. (Sources: Census Bureau, RLIS)

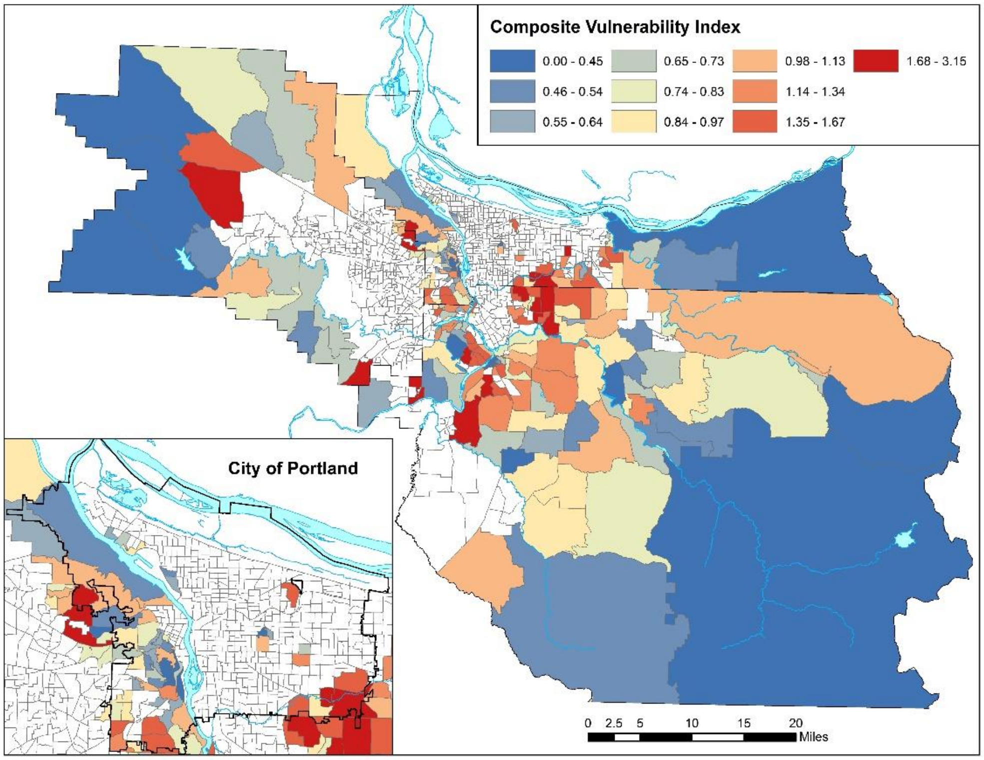


Figure 15. Vulnerability of block groups exposed to landslide hazard zones. (Sources: Census Bureau, RLIS)

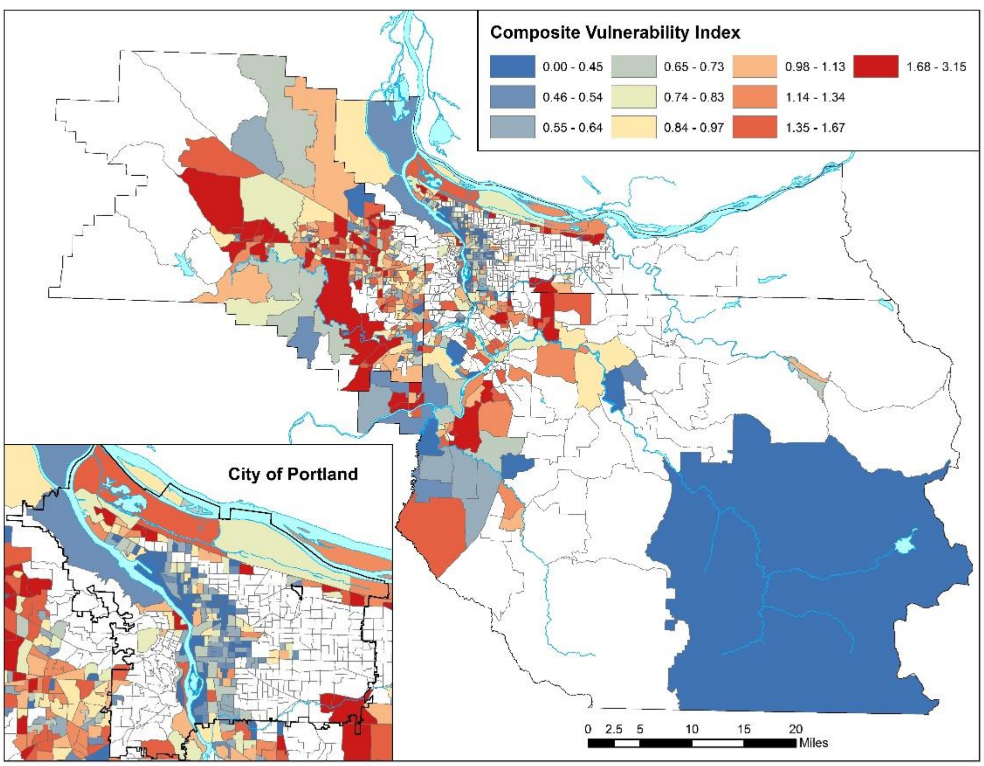


Figure 16. Vulnerability of block groups exposed to earthquake liquefaction hazard zones. (Sources: Census Bureau, RLIS)

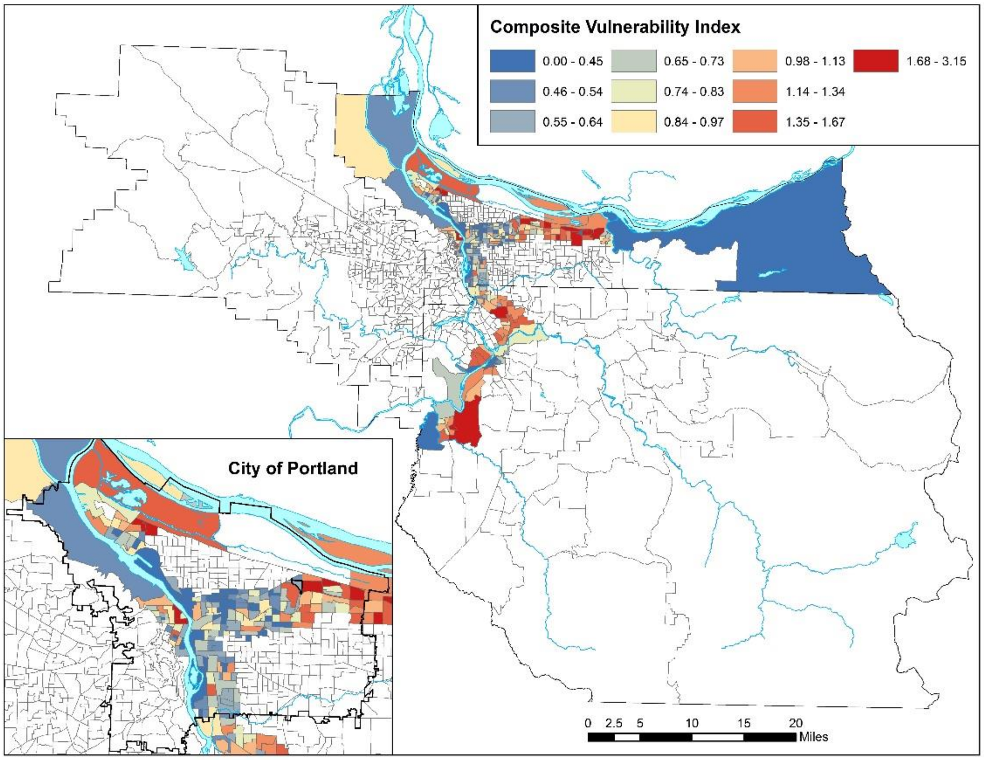


Figure 17. Vulnerability of block groups exposed to oil train hazard zones. (Sources: Census Bureau, RLIS)

Discussion

Emergency planners usually desire to have hazard exposure analyses performed at a finer scale than the census block group level (such as the subdivision or tax lot level) so that they can locate the targeted population more precisely in their emergency response plans. The maps presented at the census block group level should be interpreted with the knowledge that the socio-demographic characteristics within individual block group boundaries are not uniform and do not match the mapping units used in the hazard exposure analysis. This is specifically relevant to those places within the urbanized metropolitan area where development is non-residential (such as industrial districts) or where development has been restricted (such as regional parks or natural reserves). In particular, the well-defined hazard zones of floodplains are largely vacant of residential neighborhoods – with the exceptions of Hayden Island, Sauvie Island, and some agricultural properties alongside the Tualatin River – and many of these areas have been preserved as open spaces. Therefore, it is reasonable to infer that the exposure analysis of flood hazards may represent an overestimate of the population at risk. In a comparable manner, landslide hazard zones are found in areas where steep terrain usually prevents dense development (though adjacent areas can still be exposed), and the extent of a landslide event is typically smaller than the hazard zone. In contrast, hazard zones associated with earthquake liquefaction susceptibility cover a broader extent than those from any other hazard analyzed, and many of these zones overlap urban developed areas. Liquefaction risk is a function of soil type and ground hydrology, making it difficult to delineate precisely. Furthermore, it bears mentioning that liquefaction is only one of several earthquake-related hazards (such as ground-shaking or landslides), and it is plausible for more than one of these to occur simultaneously, potentially expanding both the area and the population at risk.

As natural hazards exhibit differing spatial patterns, they also vary in terms of their temporal characteristics, either in their comparative speeds of onset or in their rates of diffusion, and these cannot be adequately addressed with only an exposure analysis. Naturally-occurring floods are typically triggered by heavy and/or sustained precipitation, and therefore the risks associated with flooding can be monitored with stream gauges and predicted with weather forecasting. Similarly, wildfires often start from a single ignition event and spread outward, the rate of which is usually dependent on weather and available fuel. Both of these hazards serve as example of a gradual speed of onset, for which evacuation from a hazard zone is a feasible and normal emergency response action. In the case of landslides, researchers may be able to determine which places are susceptible based on geology and slope, but the capability to predict the precise location or extent of an imminent landslide presents a greater challenge. Earthquakes have proven to be among the most elusive natural hazards to predict in terms of probability, magnitude, extent, or location; as with landslides, the best research completed to date can only discern the susceptibility of a given place to various earthquake-related hazards. The risk of an oil train accident, along with the risk of a spill and/or fire, is highly problematic as it is almost entirely based on human actions and errors.

Another challenge that became evident from the exposure analysis was the irregular geography of the census block groups. This unit of analysis was chosen in order to evaluate several indicators of social vulnerability, including data not available at the block level. While the vast majority of block groups (approximately 80-90%) are relatively small and compact, allowing for a more straightforward exposure analysis, the larger block groups often contain multiple hazard zones with varying levels of risk, in addition to (presumably) diffuse patterns of population and development. On the other hand, all of the larger block groups are located at the edges of the three-county study area, and because these areas are thinly populated to begin with, they typically did not weigh significantly into the vulnerability or risk analyses.

The role of hazard mitigation also deserves some consideration in relation to the overall assessment of risk for the metropolitan area. Some natural hazards allow for possible measures of mitigating against potential damages or losses (see Table 3). The most common example of hazard mitigation is the construction of levees to control flooding. (This was accounted for in the FEMA data and, therefore, in the hazard analysis as well.) Levees were built along the Columbia River decades ago to prevent flooding and facilitate development; there are also levees and drainage pumps in place along the Columbia Slough and Multnomah Channel, and there is a seawall on the west bank of the Willamette River in downtown Portland. Each of these projects provides protection from most flooding (when properly maintained), though they can still be vulnerable to catastrophic events. Wildfires can also be mitigated in a variety of ways, such as creating defensible spaces, using safe burning practices, and managing flammable vegetation.

Table 3. Overview of hazard types, characteristics, and possible mitigation actions.

Hazard Type	Speed of Onset	Spatial Extent	Possible Mitigation Actions
Flood	Hours to days	Floodplains; low-lying areas near rivers, streams, or lakes	Construction of levees, flood walls, and/or drainage systems; elevation of homes or businesses above ground level
Wildfire	Hours to days	Forests, woodlands, or other densely-vegetated areas	Clearance of defensive space around structures; management of vegetation; safe burning practices
Landslide	Minutes to hours	Steep slopes; areas of loose soil	Stabilization of steep slopes in developed areas
Earthquake	Seconds to minutes	Varies by magnitude – ground motion possible for hundreds of miles, damage possible for tens of miles	Structural reinforcement of brick and stone masonry buildings; retrofitting of bridges and overpasses
Oil train spill / fire	Seconds to minutes	Within one mile of site of derailment or collision	Safe operation and maintenance of trains; upgrade of oil tanker cars

Regions at risk of wildfire within the study area also benefit from their proximity to numerous firefighting resources in the nearby cities. Earthquake hazard mitigation is often more complicated and typically more relevant to the construction of an individual building, roadway, or other component of infrastructure.

There are several communities which warrant a more detailed risk assessment because of their location within multiple types of hazard zones and their high indices of social vulnerability. The Old Town and Pearl districts in Portland's city center are mostly contained by the 500-year floodplain, are at medium to high risk of earthquake liquefaction, and lie entirely within a half-mile of an oil train route. (The block group containing the Old Town District also includes Portland's Chinatown District, but this district is mostly commercial and non-residential.) The Pearl District owes its high composite VI to its high population density and a relatively high number of seniors, while the Old Town District has the highest number of low-income households in the study area. The Northwest Heights neighborhood – on the west slope of the West Hills – is at high risk of landslides and moderate risk of wildfires; it also has a large number of families with children. The Pleasant Valley neighborhood is located in the southeast corner of Portland, encompassing the area along Johnson Creek between Mount Scott and Powell Butte – an area at medium-to-high risk of all four of the natural hazards studied. The neighborhood overlap with the bulk of six block groups, two of which have high composite VIs due to large numbers of children and seniors and moderate numbers of Asian-Americans. Just south of Pleasant Valley, the city of Happy Valley contains several areas at risk of wildfires (moderate), landslides (high), and earthquake liquefaction (low to high), though these hazard zones are fairly small and dispersed throughout the city and its environs. Three of the city's six block groups rank high in vulnerability due to large numbers of children and Asian-Americans.

The inclusion of race/ethnicity as an indicator of social vulnerability is potentially controversial because it presents certain assumptions regarding the definition of racial groups and the nature of their vulnerability to disaster events. The common factors influential to social vulnerability which are most relevant to race/ethnicity are a lack of access to resources and information and limited access to political power, and it is for this reason that this indicator of vulnerability is often identified through much of the geographical and sociological literature on hazards and disasters. However, it is important to understand that 1) ethnic groups within broader racial categories (black, Asian, Hispanic, etc.) do not always exhibit identical measures of economic or political disadvantages, and 2) individual members of any one racial/ethnic group do not necessarily have the same characteristics or experiences as the group as a whole. Other factors that can intensify or diminish social vulnerability among racial or ethnic minorities include the length of residency within the United States (for immigrants), the ability to speak and read English well, the degree of education, the strength of a particular community's social network, and the relationship between the residents of a community and political leaders. Consider the following hypothetical examples: a Mexican-American citizen representing the third generation of his family to live in the U.S. is likely less vulnerable to a disaster event than a Honduran immigrant who arrived to the U.S. within the last three years; a Chinese graduate of a U.S. university is likely less vulnerable to a disaster event than a Cambodian refugee separated from her family.

This study also demonstrates the use of GIS in risk analysis. Even though the risk and vulnerability models presented might not be universally applicable, the flexibility and efficiency of GIS allow emergency planners to quickly and interactively perform alternative analyses under different hazard scenarios. ESRI's ArcGIS Desktop software (version 10.2) was used to carry out the analysis. The models used in this research can be streamlined with ArcGIS programming scripts (e.g., ArcPy or Python script) or geoprocessing models created in the ModelBuilder application. As a result, complex risk and vulnerability analysis can be performed in GIS by users with limited GIS skills.

Conclusion

The purpose of undertaking a comprehensive risk analysis for a particular region is to facilitate equal consideration to the potential impacts of environmental hazards and variable levels of social vulnerability. The analysis of risk conducted for the Portland metropolitan area revealed complex patterns of exposure to multiple hazards and vulnerability based on several demographic indicators. In general, the overlay between areas of significant hazard exposure and areas of high social vulnerability is limited to small portions of the study area, and these locations have been qualitatively analyzed in greater detail. The challenges inherent with exposure and vulnerability analyses performed at the census block group level have been documented; further research into improved spatial analysis techniques for these processes would be valuable.

It is anticipated that the results of this study will provide beneficial information to the emergency management community and have the potential to enhance the ability of policy makers to communicate risks to the most vulnerable communities. While substantial research has been and continues to be accomplished with respect to exposure to environmental hazards in metropolitan Portland and the state of Oregon (primarily at the federal and state levels), there is currently a lack of research within the geographical literature addressing social vulnerability in the same areas. This study demonstrates the necessity for further research by geographers with backgrounds in physical systems, human ecology, social systems, and GIS techniques, all of which are critical to understanding and responding to the complex problems presented by environmental hazards.

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Appendix – Emergency Management Planning Guide

The following document represents a draft of an emergency management planning guide, with a focus on a specific community within the Portland metropolitan area. It is intended for potential use by local emergency managers, community leaders, or individual residents.

Environmental Hazards and Social Vulnerability in Metropolitan Portland

Community Profile – The Old Town and Pearl Districts

The greater Portland region represents a major U.S. metropolitan area and a regional industrial and transportation center, and as such it is particularly vulnerable to the impacts of a potential emergency or disaster event. With a dense population and high level of economic development, each of the municipal governments in the region (cities and counties) possess a comprehensive response plan in order to assess local environmental hazards and prepare for possible disaster events.

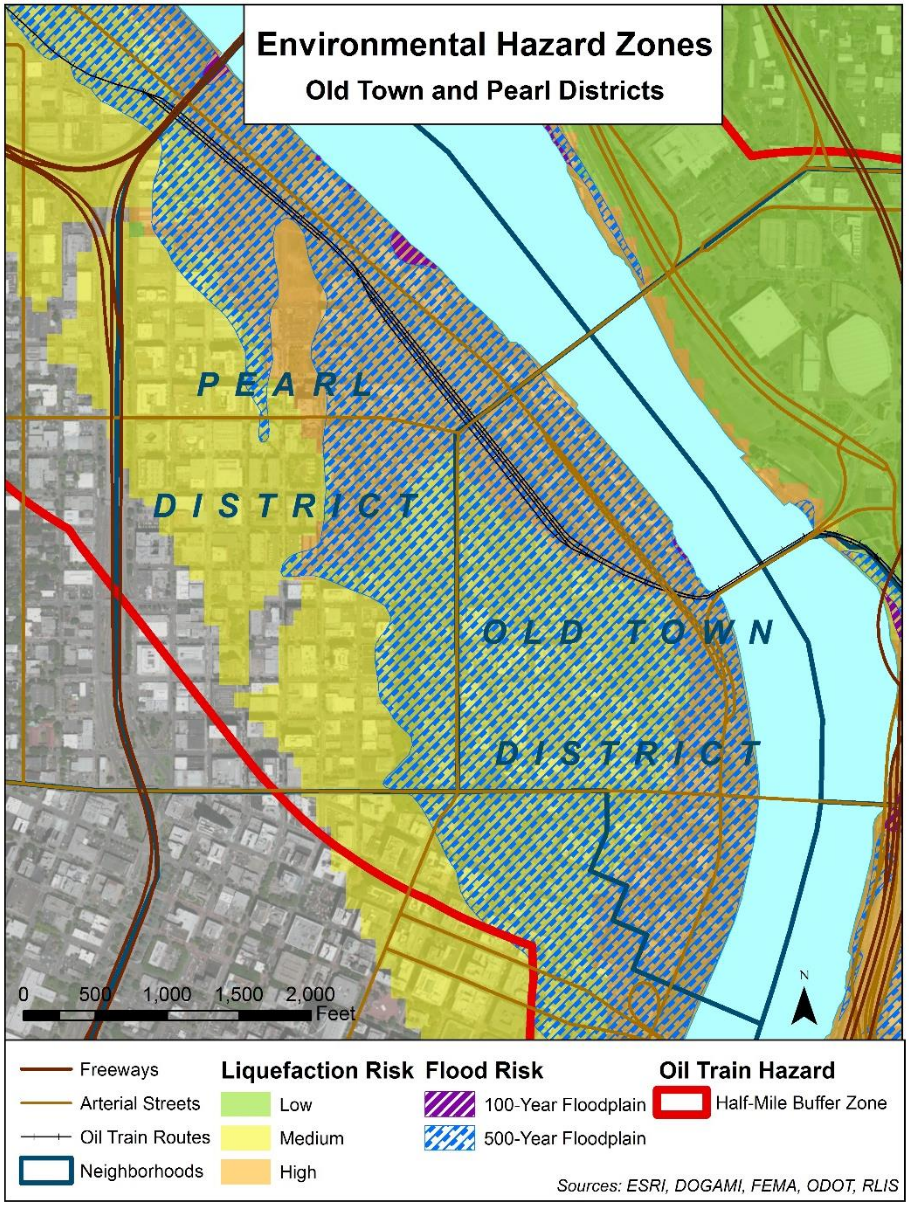
The physical geography of the Portland region contains a variety of natural hazards. Some of Portland's most recognizable natural landmarks are often the source of hazards as well, such as the Willamette and Columbia rivers and the volcanic Cascade peaks of Mount Hood and Mount St. Helens. The history of local flood events is well documented, while landslides have also been frequent and familiar to the area. While wildfires are typically more common in rural areas, some have occurred near metropolitan communities near Portland, including two wildfires occurring earlier this year. The Portland region has witnessed a significant number of disaster events since the mid-20th century, including the 1948 Vanport flood, the 1962 Columbus Day storm, the 1980 Mount St. Helens eruption, and the 1996 Willamette Valley flood.

While the region does not have a prominent history of earthquake events, it is not immune from them. In 1993, a 5.6-magnitude earthquake struck the town of Scotts Mills in Clackamas County, causing substantial damage in the surrounding area. Numerous studies have examined the seismic activity and history of the Cascadia subduction zone, which could generate an earthquake strong enough to impact the coast and valleys of the entire Pacific Northwest. More recently, a team of geologists has discovered a series of three potentially active faults within the city limits of Portland.

In addition to the natural hazards existent in the region, increasing attention should be given to a growing technological hazard and the risks that it poses to the population. There has been an increasing amount of railroad traffic transporting crude oil from North Dakota to port terminals in the greater Portland region and elsewhere in the United States. This increase in traffic has come with a sharp rise in the number of accidents involving oil trains, including three incidents within the past year. (A major explosion in the Canadian province of Quebec killed 47 people.) The spike in rail traffic – and a lack of state or federal regulatory efforts to keep pace with it – represent a growing hazard to many communities near major rail lines and terminals.

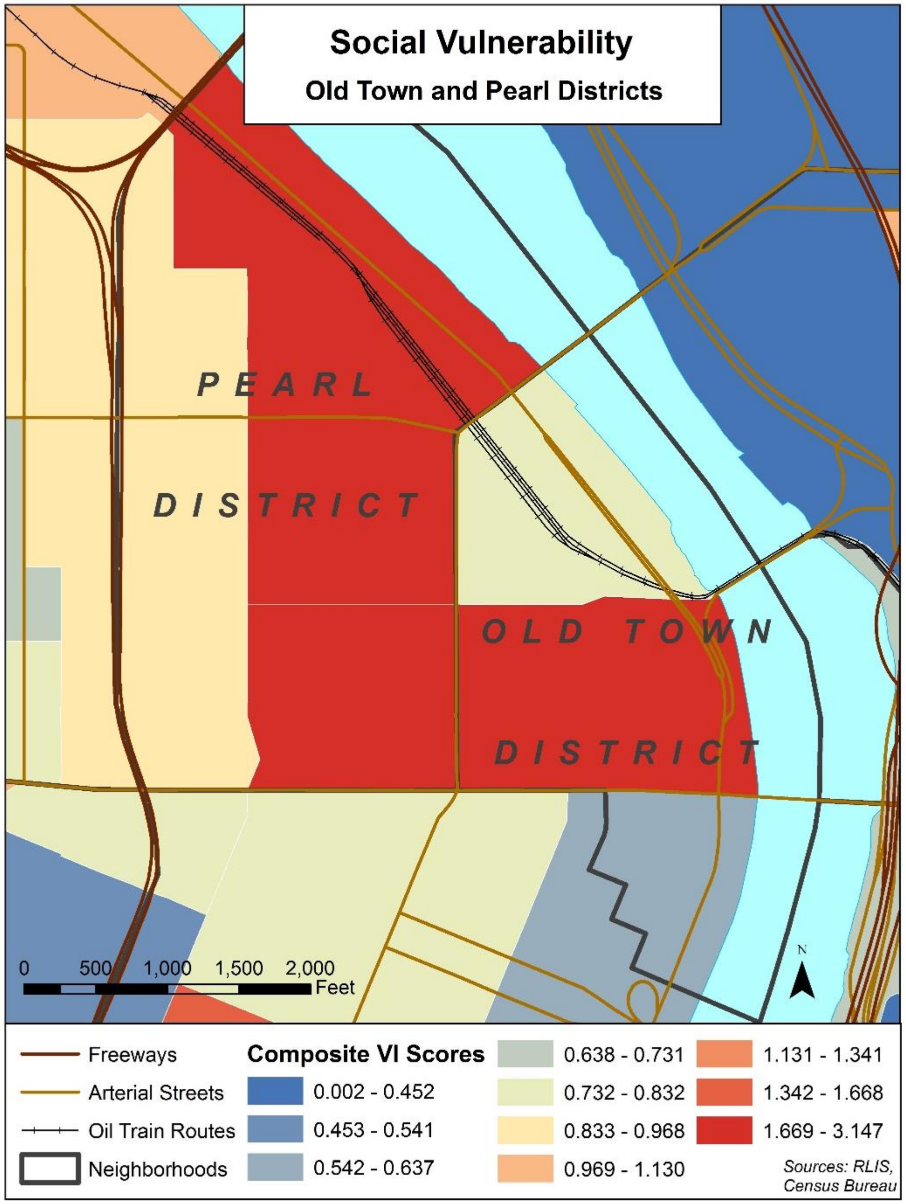
This pamphlet is based upon a geographical research paper which documents a case study in hazard exposure and social vulnerability analysis. A geographic information system was used to determine areas and populations exposed to five environmental hazards within the Portland metropolitan area: floods, wildfires, landslides, earthquake liquefaction, and oil trains. Social vulnerability was assessed by using five demographic indicators: total population, age (under 18 and over 65), race/ethnicity (minorities), and low household income. The results of the study revealed broad variations in exposure to different hazards, while they also suggested that several areas show a combination of high levels of vulnerability and exposure to multiple hazards.

Two such communities which deserve a more detailed risk assessment are the Old Town and Pearl districts in Portland's city center (shown at right). Both neighborhoods are mostly contained by the 500-year floodplain, with a small pocket in the 100-year floodplain (near the end of NW Ninth Avenue). They are also at medium to high risk of earthquake liquefaction, due to their location on soft alluvial soil. This area lies almost entirely within a half-mile of an oil train route. While most of the crude oil transported through the region passes through North Portland, an unknown number of trains also move through the city center.



Social vulnerability was determined first by counting the population of each vulnerable demographic group (plus total population) in every census block group in the metropolitan area, and then by assigning a vulnerability index (VI) score to each block group. Each demographic indicator was normalized by calculating a ratio of a given attribute in a block group to the total number for the whole study area. The ratio was then divided by the highest ratio found in the study area in order to produce a block group's vulnerability index (VI), ranging from 0 to 1. All values were added together to provide a composite VI for each block group, which enabled an overview of social vulnerability for the metropolitan region.

While the neighborhood boundaries do not completely match the designated census block groups, it is clear that the Pearl and Old Town districts together include two of the most vulnerable block groups in the metropolitan area (shown at right). The Pearl District owes its high composite VI mostly to two factors: its high population density and its relatively high number of seniors. The Old Town District has the highest number of low-income households in the study area. This part of the city also contains Portland's Chinatown district, but this district is mostly commercial and non-residential. Population totals for the three block groups completely contained by both neighborhoods, along with the totals for each vulnerable demographic group, have been organized into a table (next page).



Vulnerable Populations in Pearl and Old Town Districts (figures from partial block groups not included)						
Block Group (Tract #)	**District Area**	**Total Pop.**	**Youth Pop.**	**Senior Pop.**	**Low-Income Households**	**Minority Pop.**
Block Group 1 (5100)	North & central Pearl Dist.	3,370	182	437	575	631
Block Group 2 (5100)	South Pearl Dist., central Old Town Dist.	3,202	62	272	1,175	853
Block Group 3 (5100)	North Old Town Dist.	1,354	56	97	283	344
Total		**7,926**	**300**	**806**	**2,033**	**1,828**

Given the degree to which certain neighborhoods like the Pearl and Old Town districts (and others) are exposed to several environmental hazards and include significant populations of vulnerable social groups, it is worthwhile for emergency planners to consider focusing limited resources toward those communities at the greatest risk of losses from disaster events. It is also important to understand that each environmental hazard can be mitigated in some way. Flood risks can largely be managed with the construction of levee or floodwall systems. While there is a floodwall in place along the west bank of the Willamette River protecting downtown Portland, it only extends to the Steel Bridge, leaving the newer riverfront residential developments more exposed to the north of the bridge. In the case of earthquake risks, mitigation involves the reinforcement of existing stone and brick masonry buildings along with earthquake-resistant construction techniques used in most contemporary structures. Both building types can be found among most of the buildings in these neighborhoods. The mitigation of oil train hazards (spills or fires) mainly depends on the proper operation of trains travelling through Portland and the proper maintenance or upgrading of oil tanker cars; existing regulations should also be revised to adapt to the current levels of rail traffic involved in the shipment of crude oil.

The results of this study will hopefully provide beneficial information to the emergency management community and enhance the ability of policy makers to communicate risks to the most vulnerable communities.

Further Reading

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